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PIEDMONTITE IN ARIZONA

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Piedmontite the rare manganese member of the epidote group was first described from Arizona by Dr. C. Lausen in 1927.[1] This occurrence was in andesitic rock on the southeast slope of Pat Hills in the Sulphur Spring Valley about 25 kilometers northeast of Pearce, Arizona. It was later discovered by Dr. W. H. Brown in the Tucson Mountains immediately west of Tucson in rhyolitic rocks associated with sandstone or quartzite,[2] and still later, in 1934, by the present writer in the Santa Rita mountains about 50 kilometers south of Tucson. This paper contains a brief description of the Santa Rita occurrence as well as a more detailed account of the striking features displayed in the Tucson Mountain deposits. The latter is given greater prominence on account of its greater distribution as well as its more remarkable paragenetic interest.

Piedmontite seems to have been known to Cronstedt in 1758 from its earliest locality, Piedmont, Italy. He refers to it as "röd Magnesia." This work appears to have been forgotten until 1790, when Napione refers to it as "Manganèse rouge" and publishes analyses. On the basis of these analyses, Haüy in 1901 gave it the name of "Manganèse oxydé violet silicifère." In 1803, Cordier from the results of new analyses renamed it "Epidote Manganésifère," a name which was adopted by Haüy. Thus at this early date the true nature of the mineral was appreciated. Later the mineral became known as "Piedmontischer Braunstein" and finally as Piedmontite.[3]

A specimen of piedmontite from San Marcel, Piedmont, Italy, in the writer's possession appears as a schistose or gneissic rock consisting chiefly of quartz and piedmontite, the latter being oriented according to the schistosity of the rock. It is also found in mica schists on the Island of Groix and in the chlorite and glauco-

[1] Lausen, C., Piedmontite from the Sulphur Spring Valley, Ariz.: *Am. Mineral.*, vol. **12,** pp. 283–287, 1927.

[2] Personal communication.

[3] Hintze, C., *Handbuch der Mineralogie* II. p. 254.

phane schists of Japan.[3] Rosenbusch claims it as a petrographic mineral as shown by his use of the terms, Piemontitschiefer, Piemontitphillite and Piedmontitquarzit.[4] On the American Continent, Williams described it from the rhyolites of South Mountain, Pennsylvania,[5] and Harworth from the quartz porphyries of Annapolis, Missouri.[6] Rogers also found it in thin sections of quartz porphyry from a boulder in gravels at Pacific Beach, San Diego Co., California.[7] More recently Mayo describes it as occurring in a "piedmontite sericite schist of volcanic origin" from near Shadow Lake, Madera Co., California, in crystals .2 to .3 mm. in length. It was also found in a second locality in the same county replacing biotite in a similar rock.[8] Material from this locality was further investigated as to optical properties of piedmontite and their relation to manganese contents, by A. M. Short.[9] It would seem, then, that its appearance in rhyolitic rocks or closely related volcanics is perhaps its most characteristic mode of occurrence in this country.

In the Santa Rita mountains south of Tucson, Arizona, the writer has found piedmontite in two localities some fifteen kilometers apart. The first found in 1933 was in a nearly white pebble of rhyolitic composition found in an arroyo about six kilometers from the Helvetia copper mines, on the Helvetia-Vail road. The microscope revealed in a thin section only three or four spots of piedmontite in a rock of felsitic texture. The pebble must have been transported several kilometers and no information is available as to its source. The other occurrence in the Santa Rita Mountains was in a dull reddish gray rhyolitic rock in a small canon leading from the east into Madera Canon. The rock was a large angular boulder associated with many others of the same composition and had been transported but a short distance. In fact it

[4] Rosenbusch, H., *Elemente der Gesteinslehre*, 4te Auflage (Osann), pp. 697, 744, **1923.**

[5] Williams, G. H., Piedmontite and Scheelite from the Ancient Rhyolites of South Mountain, Pa.: *Amer. Jour. Sci.* (3), vol. **46,** pp. 50–57, 1893.

[6] Harworth, E., *Am. Geologist*, vol. **1,** p. 365, 1888.

[7] Rogers, A. F., Notes on Rare Minerals from California: *School of Mines Quart.*, vol. **33,** p. 373, 1912.

[8] Mayo, E. B., Two new Occurrences of Piedmontite in California: *Am. Mineral.*, vol. **17,** p. 238, 1932.

[9] Short, A. M., A Chemical and Optical Study of Piedmontite from Shadow Lake, Madera Co., California: *Am. Mineral.*, vol. **18,** p. 493, 1933.

probably had broken from the sides of the canon which were also of the same general composition. The piedmontite occurred in a rounded inclusion, of about 10 mm. in diameter, but of unknown original composition. This was almost completely replaced by piedmontite and sericite, the latter being in rather long plates. The area immediately surrounding the inclusion also contained a few inconspicuous grains of piedmontite as well as what appeared to be specular iron. Neither one of these specimens was known to contain piedmontite at the time of discovery but later investigation in the Madera Canon locality proved that specimens of piedmontite-bearing rhyolite can quite easily be secured, the material being limited to loose blocks. The piedmontite then appears as spots or segregations in the rhyolite rock, the matrix itself being rather coarser grained than the similar occurrence in the felsitic rocks of the Tucson Mountains.

In the Tucson Mountains piedmontite occurs in a series of steep quartzite or sandstone peaks and ridges about 1½ kilometers in length extending in a NW to SE direction in what is known as the Tucson Mountain Recreational Area. Its most northly end begins almost exactly at the picnic grounds known as Juan Santa Cruz near the Recreational Headquarters. While the flanks of the peaks and ridges are mainly quartzite or sandstone, some of the summits and crests of the ridges are occupied by a dense pinkish rock of rhyolitic composition, perhaps best designated as felsite. The intrusion of this volcanic mass is probably the direct cause of the sandstone hills. Where the summits are occupied by sandstone perhaps represent places where the intrusion was unable to break through, or else where it has not been exposed by erosion. The felsite is usually very close grained, sometimes breaking like chert into fragments with conchoidal fracture and sharp flint-like edges (Fig. 7). A few phenocrysts of feldspar a millimeter or so in cross section are present but usually very inconspicuous. Its micro-texture, then, seems to prove it to be a cryptocrystalline mixture of quartz and feldspar with frequent clusters of purer quartz much of which is probably a later segregation in the intrusion. Minute veinlets of irregular shape consisting of the same type of quartz are also frequent. The felsite contains inclusions of other volcanics apparently more basic than itself, as well as sandstone probably picked up as it broke through the sandstone series. As the sandstone in places is extremely rich in such volcanic inclusions, the felsites may have obtained theirs from that source.

Almost everywhere in the area under discussion the felsite or rhyolitic rock contains spots of piedmontite clusters of a fine red color when viewed in a strong light. When occurring in larger clusters not mingled with too much clear quartz, the color of the piedmontite is a deep purplish red or brown.

The quartzite or sandstone with which the piedmontite felsite is associated varies in color from buff to dark brown and gray. It also varies greatly in structure from an even fine grained rock, sometimes showing stratification, to a coarse type breaking with a rough surface. In thin sections it often appears with subangular quartz grains of ununiform sizes with a varying amount of cement. In many places, especially near the felsite areas, it is highly arkosic containing many grains of orthoclase, plagioclase and microcline with a cement much resembling the groundmass of quartz porphyries. Indeed it is sometimes so altered as to resemble in thin sections, as well as hand samples, a porphyrite rhyolite or even an aplitic rock. The angular appearance of the quartz, though sometimes lacking due perhaps to resolution, as well as field relations furnish the best criteria. Moreover many volcanic inclusions are present in places but not at all evenly distributed. They consist mainly of rounded pebbles of a porphyritic rock probably of andesitic composition and often in sufficient quantities to give the rock a highly conglomeratic appearance. Thin sections of this sort of material, especially where it is highly silicified and otherwise altered, exactly resemble igneous rocks. It might even be called by some a volcanic breccia but it is believed really to belong to the sandstone series.

The occurrence of the piedmontite in the felsite-sandstone area of the Tucson Mountains may perhaps best be described under the following six types:—

(1) As spots or rounded and lenticular segregations in felsite.

(2) As minute veinlets in felsite a millimeter or two in width and a few centimeters in length.

(3) As replacements of inclusions in felsite, or simply as borders surrounding them.

(4) In veins or stringers of white quartz in both felsite and sandstone, the latter being the better developed.

(5) Associated with calcite in a manner somewhat similar to (4) but of rare occurrence.

(6) As replacements of some of the constituents of sandstone,

and volcanic inclusions therein contained, in the vicinity of the vein system.

The first mode of occurrence is illustrated in Figs. 1, 2, and 3. These are clusters of piedmontite crystals showing in thin sections the usual beautiful trichroism, mingled with quartz which seems to be characteristically segregated near the center of the spot. In Figs. 1 and 2 the less well crystallized borders contain considerable common epidote. These spots vary in size up to about ten millimeters in cross section. Sometimes the crystals of piedmontite

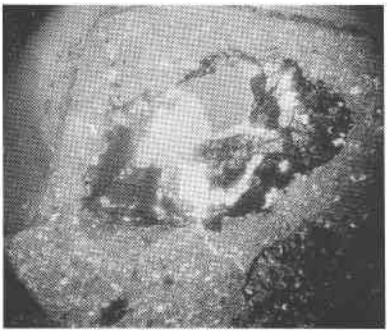

FIG. 1. Thin section of felsite, nicols partially crossed, showing a piedmontite-quartz cluster. ×10.

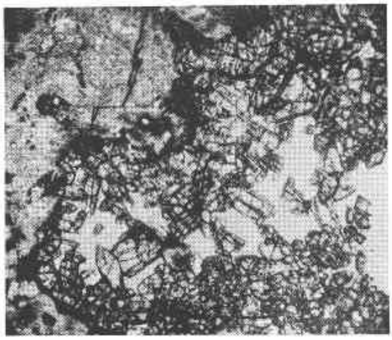

FIG. 2. A larger cluster of piedmontite in felsite. White is quartz, dark with cleavage is piedmontite and mottled with large fracture is felsite. ×10.

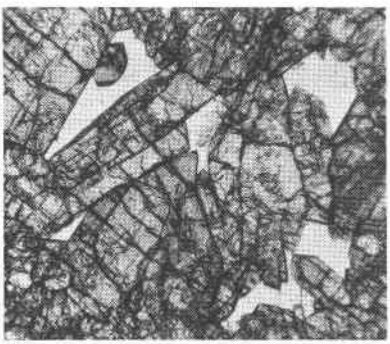

FIG. 3. A photograph of the same as Fig. 2 but with higher power to show texture of piedmontite crystals. Ordinary light. ×36.

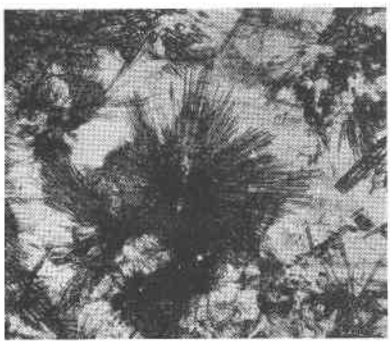

FIG. 4. An illustration to show the frequent stellated habit of piedmontite. White is quartz. Ordinary light. ×34.

when extending towards the center into quartz may be "terminated" by two prominent faces which, as the crystals are usually elongated in the direction of the *b*-axis, are taken to be in the prism zone. Several of these have a normal angle of near 116° as measured by the microscope. Sometimes in place of the spots there are cavities lined with quartz, piedmontite and rarely hyalite, together with such decomposition products as manganese oxide and a kaolin-like mineral. These segregations are thought to represent a concentration of manganiferous material from the body of the felsite itself rather than a migration of manganese from extraneous sources. As discussed later the felsite notwithstanding the fact that it is piedmontite-bearing in practically every place throughout the area, is not abnormally rich in manganese. After the period of vulcanism, some undetermined feature of the hydrothermal solutions segregated the manganese in the form of the epidote molecule from the not unusual traces already present. The felsite as well as the associated sandstone contain numerous black grains, like black sand. Some are magnetic but many are not. They do not react appreciably for manganese.

The second mode of occurrence, that of minute veinlets in felsite, is not materially different from the first except that it emphasizes the fact that the piedmontite has been a later segregation although not necessarily brought in from outside sources. The veinlets may be wandering or they may follow a definite fracture plane. In the latter case the rock may cleave along this plane yielding a surface of pleasing reddish color. This appearance may be enhanced if the surface contains numerous minute quartz crystals. These surfaces show sometimes small red slickensides with striations. On making thin sections of these veinlets as well as the piedmontite spots, the operator is sometimes surprised to find the specimen much leaner in the red mineral than he expected. The minute quartz crystals when backed by piedmontite are frequently taken for the manganese mineral.

The third type of occurrence or the more or less complete replacement of inclusions in felsite is quite common in the Tucson Mountain area. The inclusion may be more or less spotted by the red mineral or crossed by veinlets sometimes forming a net-work. The most characteristic procedure, however, seems to be that of replacements around the border, the piedmontite appearing as rims completely surrounding the inclusion. This type should not be confused with the brecciated inclusions in quartz veins to be described later in which there are still more striking arrangements of the piedmontite as narrow fringes (Figs. 11 and 12). Feldspars in the volcanic inclusions in the felsite have been observed in thin sections partially replaced by piedmontite. Often the whole inclusion has been replaced as described above from material from the Santa Rita Mountains, and there remains only piedmontite and other less rare replacing minerals.

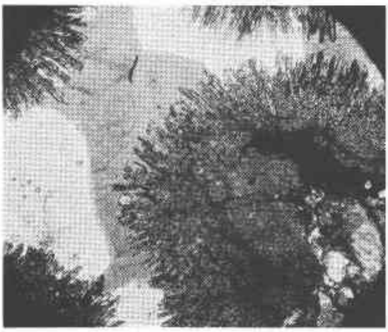

FIG. 5. Fringes of piedmontite on inclusions in quartz veins. Nicols partially crossed. Only a portion of the inclusion can be seen at the lower right. See Figs. 11 and 12 for better display of inclusions and piedmontite fringes. ×25.

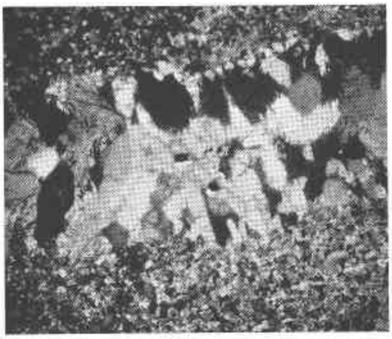

FIG. 6. Veinlet of piedmontite and quartz in sandstone. Note stellated clusters of piedmontite extending from borders of vein into quartz. Nicols partially crossed. ×12.

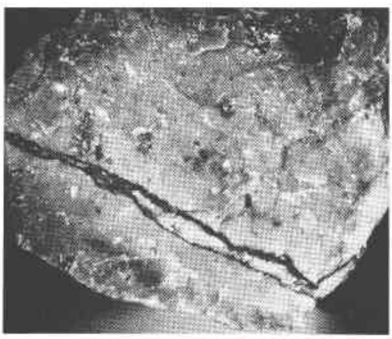

FIG. 7. A photograph of a megascopic specimen of piedmontite-quartz veinlet in dense felsite. Dark borders are piedmontite. ×0.8.

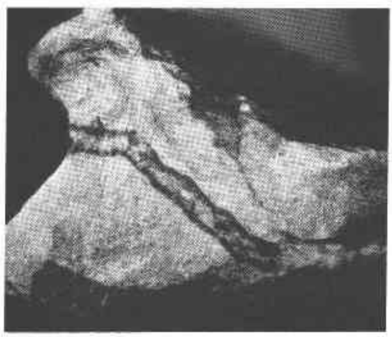

FIG. 8. A similar veinlet of piedmontite and quartz in sandstone still showing the dark borders of piedmontite. ×1.0.

The fourth type, perhaps the most interesting of all, is that of a series of veins starting in the felsite and extending into the sandstone. This occurrence has been well developed in only one place in the Tucson Mountain area, and is illustrated in thin section in

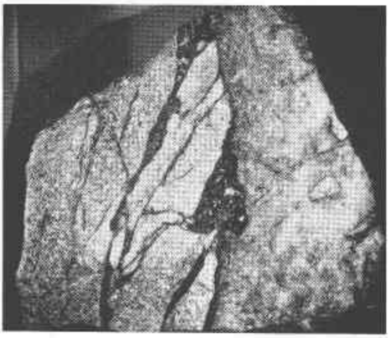

FIG. 9. A photograph of a megascopic specimen showing quartz vein material at right, with country rock (sandstone) crossed by numerous veinlets of piedmontite to the left. Note a few inclusions in the vein material with borders of piedmontite. Such inclusions are better illustrated in Figs. 11 and 12. ×0.7.

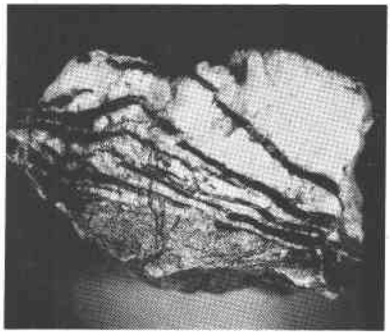

FIG. 10. Another view of quartz vein material, showing gashes of later piedmontite. This is purer than other types found in the Tucson Mountains and was chosen for the chemical analysis. Note portion of wall rock at bottom. ×0.7.

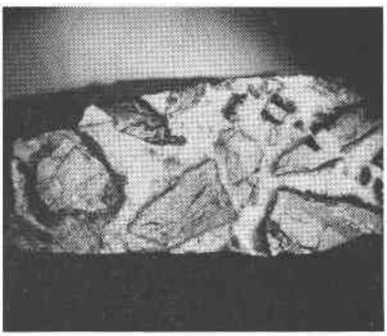

FIG. 11. A typical view (megascopic specimen) of the wider portion of one of the quartz veins, showing inclusions of the wall rock all of which are completely bounded by a narrow fringe of piedmontite. For details in the texture of the fringes see Fig. 5. ×0.4.

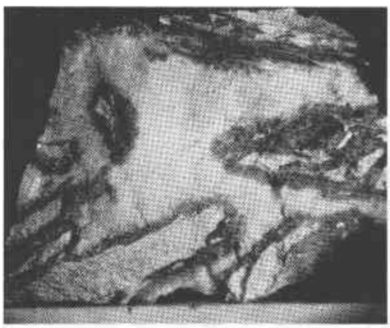

FIG. 12. Same as Fig. 11 but showing inclusions in white vein quartz crossed by piedmontite and, in fact, more completely replaced. ×0.7.

All illustrations accompanying this paper are from the Tuscon Mountains, Arizona.

Fig. 6 and in megascopic specimens in Figs. 7–12. The vein is really a series of narrow stringers of white quartz and piedmontite originating in felsite. Any one stringer may attain a width of 12 cm. while the series may be a meter in width, and is traceable for 25 meters or more. They are exposed on the face of two small cliffs one above the other the lower consisting of sandstone and the upper of felsite. Large blocks broken from the face of the cliffs have yielded the best specimens. The larger white stringers of quartz appear very prominently spotted due to the presence of many subangular inclusions from the sandstone series. These spots may vary from minute fragments to those several centimeters in cross section. The piedmontite appears as striking fringes on practically all of these inclusions. These are shown in photographs of megascopic specimens in Figs. 11 and 12. If the inclusion is small or if the break crosses a narrow portion of it, the spot may be made up entirely of piedmontite. On weathered surfaces the inclusions have all taken on a rather uniform purplish black color presenting a strong contrast to the white quartz. On freshly broken surfaces the fringes of piedmontite correspond to Vandyke Red 1′ Red k,[10] and may vary from one to several millimeters in thickness. Yet when examined by a hand lens in a strong light or in thin sections the color is that of a rich ruby red. A photomicrograph of some of these fringes together with a small portion of the inclusion is shown in Fig. 5. The quartz stringers may also have later gashes of purer piedmontite of considerably darker color or near Dark Mineral Red 1″ Red m, the difference in shade being due to the amount of quartz present. These piedmontite gashes may reach a width of two centimeters and being freer from impurities than the fringes on inclusions or the spots in felsite were chosen for the selection of material for the analysis given in the table.

Silica, lime and alumina correspond rather closely to material analyzed by Takayama[11] while manganese in considerably higher, but the sum of iron and manganese sesquioxides is almost identical. Manganese is only slightly lower than in piedmontite from California recently analyzed by Kameda[9] but higher than the partial analysis (8.91%) by Dr. Buehrer in piedmontite from Sulphur Spring Valley, Arizona.[1] Manganese is lower than in six of the seven analyses in Hintze's Handbuch. The RO-R_2O_3-SiO_2 ratio

[10] Ridgway, R., *Color Standards and Nomenclature*, **1912.**

[11] Hintze, C., *Handbuch der Mineralogie*, II. p. 256, (Anal. VII).

corresponds to the generally accepted figures (4-3-6) except that lime is rather high.

Analysis of Piedmontite, Tuscon Mountains, Pima Co., Arizona

Dr. Paul H. M.-P. Brinton, Analyst

Silica, (SiO_2)	37.43%
Alumina, (Al_2O_2)	21.27
Iron Oxide, (Fe_2O_3)	3.80
Calcium Oxide, (CaO)	24.75
Magnesium Oxide, (MgO)	0.00
Water, Below 110°	0.04
Water, Above 110°	0.92
Manganese Sesquioxide, (Mn_2O_3)	11.80
Titanium Oxide, (TiO_2)	0.10
Total	100.11

Material from the same sample as analyzed by Dr. Brinton was selected for determination of refractive indices and trichroism with the results given below:—

Refractive Indices of Piedmontite from Tucson Mountains, Arizona

By Dr. Esper S. Larsen

$\alpha=1.732$	Buff, 15'b. Ridgway's Color Standards.
$\beta=1.750$	Deep Vinaceous Lavender, 65'''d.
$\gamma=1.778$	Spinel Pink, 71'b.

These values are lower, β and γ considerably lower, than suggested by the curves showing the relation of manganese content and refractive indices published by A. M. Short.[12] These curves, however, contain but two determined points.

In thin sections this dark piedmontite occurring as gashes in quartz is sometimes seen to grade into a very fine grained type consisting of fine needles or fibers which further grade into material so fine as to be nearly isotropic and without pleochroism. This may pass into wavy varieties resembling agate structure but observable only in thin sections.

A few of the thicker gashes of piedmontite contain a dullish metallic mineral which from its hardness and other mineralogical tests was taken to be braunite. This is reasonably confirmed by a partial analysis by Dr. Brinton. The small amount of material available was too impure to make a complete analysis worth while. Dr. Brinton's results are as follows:—

[12] Short, A. M., A Chemical and Optical Study of Piedmontite from Shadow Lake, Madera County, California; *Am. Mineral.*, vol. **18**, p. 498, Fig. 4, 1933.

Total Silica (SiO_2)	26.82%	
Manganese Sesquioxide (Mn_2O_3)	53.18	
Insoluble residue		34.8%

The insoluble residue was largely piedmontite with quartz. A complete analysis of piedmontite from the same material made by Dr. Brinton and described above contained 37.43% silica. Therefore of the 34.8% insoluble residue, 37.43% is, disregarding other impurities, silica combined in piedmontite. This leaves 13.8 parts for silica associated with manganese sesquioxide. On recalculating to 100% we have for the braunite 79% manganese sesquioxide and 21% silica. Polished surfaces show that the braunite is roughly oriented in bands parallel to the elongation of the piedmontite gashes. It was associated with sharp acicular crystals, probably an oxide of manganese.

The above description of the vein material refers to that in the sandstone series. That portion of the vein system in felsite is somewhat different, the stringers being narrower and the quartz veins lacking the prominent brecciated condition and the resulting inclusions. Many of the stringers show striking borders of piedmontite, the centers being mainly occupied by white quartz (Fig. 7). Some of the very narrow veinlets, say one or two millimeters in width, may appear in hand specimens as all piedmontite, yet on examination in thin section are found really to have quartz in excess. The admixture of quartz seems to be the chief cause for the variability in the shade of red. The piedmontite appears as tufts of divergent crystals extending from the walls of the veinlet. Fig. 6 in thin section and Fig. 8 a photograph of a megascopic specimen show this same type in sandstone.

The fifth type of occurrence is piedmontite associated with calcite. This occurs a short distance from the quartz veins and resembles them except calcite is found instead of quartz. The formation is rather insignificant and only a few specimens are available. On examination with a hand lens the characteristic tufts of piedmontite seem to be entering the calcite in the same manner as the corresponding tufts in the quartz veinlets. On investigation in thin sections, however, the tufts are found to be distorted the separate needles being curved and many times broken and filled in by calcite. From this it is taken that calcite is later than the piedmontite and has simply replaced the quartz in the veinlet which is held to be earlier than piedmontite.

The sixth mode of occurrence, that of scattered grains of piedmontite in sandstone, probably occurs only in the vicinity of the piedmontite-quartz veins. The stray grains are about the size of the constituents, and have been observed in thin sections up to five meters from the vein. Sometimes it is paler here and associated with and grading into a near colorless epidote.

Many of the specimens described above show on weathered surfaces a thin film or black (purplish) varnish either on the piedmontite itself or the associated rock. This reacts strongly for manganese and is without doubt an oxide of manganese. Much of this does not differ particularly from the well known "desert varnish" described by Blake.[13]

Piedmontite has been described as sometimes having red centers or ends grading off into colorless or greenish borders, a phenomenon to be expected when its probable isomorphism with common epidote is considered. Lausen,[1] has described this feature in material from Pat Hills, Arizona. This is not a particularly noticeable feature in the Tucson Mountain area. A few sections do show a deep red center with an abrupt change to a colorless border, while other grains usually associated with common epidote have but the faintest pink tint.

Origin of Piedmontite from the Tucson Mountains. In the discussion of the origin of common epidote little attention need be paid to the source of the iron or other elements as they are present in notable quantities in all rocks. Naturally the source of the iron is held to be from the breakdown of the ferromagnesian minerals such as biotite, hornblende, etc. The situation seems to be somewhat different in the case of piedmontite as there are no typical manganese rock-forming minerals. Thus it might be held that by some process, not easily traceable, these piedmontite rocks became unusually rich in manganese. A determination of manganese was therefore made in the rocks of the piedmontite area including piedmontite bearing felsite and sandstones as well as two normal rhyolites of the Tucson Mountains, but outside the piedmontite district. The results are given in the table below.

Perhaps the most interesting feature brought out in the above table is the manganese content of the piedmontite felsite as shown by the first three determinations. The percentages, here calculated as Mn_2O_3, are not above those frequently reported everywhere in

[13] Blake, W. P., Superficial Blackening and Discoloration of Rocks Especially in Desert Regions: *Am. I. M. Eng.*, vol. **35**, pp. 371–375, 1905.

normal rhyolitic rocks, yet in all three piedmontite could easily be detected by a hand lens. This shows that a rock, in order to develop piedmontite does not necessarily have to contain more manganese than is found in normal rocks almost anywhere. The development of the piedmontite then must be due to some undetermined peculiarity of the geophysical conditions. It may be that these conditions are a little different than those required to form common epidote. It is therefore believed that the manganese which has given rise to piedmontite has been present in the body of the felsite and search for an extraneous source is not necessary.

Percentages of Manganese in Piedmontite Felsite and Associated Rocks from Tucson Mountains, Arizona

Dr. Paul H. M.-P. Brinton, Analyst

No. 1.	Piedmontite Felsite, south end	0.14% Mn_2O_3
No. 2.	Piedmontite Felsite, near center	0.07
No. 3.	Piedmontite Felsite, north end	0.07
No. 4.	Conglomerate sandstone, south end about 8 meters from a felsite intrusion	0.21
No. 5.	Sandstone, even grained and showing piedmontite under microscope, 5 meters from piedmontite vein	0.05
No. 6.	Sandstone, about 300 meters from piedmontite felsite	0.25
No. 7.	Sandstone, north end	0.15
No. 8.	Pink rhyolite cliffs, about 3½ kilometers from the piedmontite felsite area	0.05
No. 9.	Normal rhyolite, Tucson Mountains, Amole Peak	0.06

Manganese was determined in four samples from the sandstone series (Nos. 4–7) distributed as indicated in the table. Rather varying amounts were found as might be expected from the variable character of the sandstone. Those remote from the piedmontite veins seemed to carry fully as much manganese as those near by, perhaps the richest being those with large quantities of volcanic inclusions. Although the sandstones are higher in manganese than the piedmontite felsites, they cannot be looked upon as the source of manganese for the genesis of the piedmontite, as it seems irrational to formulate the necessary movement of the hydrothermal solutions. Where piedmontite is found in sandstone it has been assumed that it has resulted from migrations from the felsite. Some geophysical condition associated with post-volcanic activity was the great factor in the development of piedmontite wherever found.

Manganese was determined in two rhyolites considerably removed from the piedmontite area (Nos. 8 and 9) and these were found to contain about the same amount of Mn_2O_3 as two out of three samples of piedmontite felsite. No. 8 was strikingly pink in color and it was thought for that reason it might contain piedmontite, but several thin sections failed to reveal any. No. 9 was a light gray rhyolite and represented, as compared to the felsite area a very large mass. This determination was made in order to compare the manganese content in the piedmontite felsite with normal rhyolite of the Tucson range of mountains.

Resumé

(1) One new locality for piedmontite in Arizona has been recorded, that of the Santa Rita Mountains south of Tucson, where it is found in spots in rhyolitic rock and replacing inclusions. The description of this has been brief as only few data are available at the present time.

(2) A detailed account of the occurrence of piedmontite in felsitic rock of the Tucson Mountains together with one new complete analysis and optical determinations, make up the most important part of the paper. Six types of occurrence have been described.

(3) The richest specimens of piedmontite are found where the hydrothermal solutions have converged in the form of a series of white quartz stringers into sandstone. These veins contain numerous angular inclusions of the country rock which are, almost without exception, fringed with striking layers of purplish red piedmontite. The smaller veinlets may consist of white quartz centers and piedmontite borders.

(4) The felsite itself has been considered the source of the manganese from which piedmontite has been segregated into spots and the other types of occurrence. The felsite as a whole does not seem to contain, as shown by a chemical determination, more manganese than is frequently found in normal rhyolitic rocks.

(5) The complete analysis of piedmontite, a partial analysis of impure braunite, and numerous determinations of manganese for a discussion of the geological distribution of that element in the Tucson Mountains, were made by Dr. Paul H. M.-P. Brinton, of Pasadena, California, and the determination of the indices of refraction and pleochroism were made by Dr. Esper S. Larsen of Harvard University. For this valuable assistance the writer is pleased to express his sincere appreciation.